NEW MILLENNIUM PROGRAM
SUBSYSTEM FLIGHT VALIDATION EXPERIMENT
DRAFT TECHNOLOGY REQUIREMENTS

NOTICE

The New Millennium Program (NMP) is at present planning a technology validation project opportunity for NASA's Office of Space Science. It is planned for this opportunity that we will be focusing on breakthrough technologies that can be tested essentially as stand-alone subsystem items. The technologies for this opportunity should be at a maturity level that they can be flight validated in the late FY '03/'04 time frame.

The following is a set of draft descriptions of the technologies of interest with their respective draft performance requirements. It is fully expected that the number of technologies actually identified will be further reduced based on discussions in the workshop and through subsequent program discussions with NASA Headquarters.

SUBSYSTEM FLIGHT VALIDATION EXPERIMENT
DRAFT TECHNOLOGY REQUIREMENTS

(Mission abbreviations are defined in a table at the end of this document)

Light Weight Deployables

1. (*Draft*) SOLAR SAIL DEPLOYMENT

Introduction:

Many space science missions with very high delta-V requirements are enabled or enhanced through the use of solar sails. For some of these missions even advanced propulsion systems such as ion propulsion are too heavy and use considerable propellant to execute the mission.

Before a full-up sail system validation mission is attempted, it is desirable to mitigate some key risks by performing a space flight experiment to characterize the deployment and related issues by:

- ?? Validating concepts for packaging and deploying large sails.
- ?? Demonstrating deployment of a large sail membrane and support structures in a microgravity environment to reduce risk for future sail missions. Microgravity deployment dynamics cannot be simulated in ground testing.
- ?? Characterizing structural mechanics and dynamics of a deployed sail in a microgravity environment to validate analytical models developed in ground testing.
- ?? Assessing the combined effects of the space environment on sail shape. Environmental effects include solar radiation pressure, microgravity, static charging and thermal deformations.
- ?? Validating scaling laws that will be used in the design of larger sails.

Table 1-1 shows the Solar Sail requirements of the user community planning future missions.

Table 1-1 Solar Sail Requirements

Item	Requirement
1. Films	0.5- 5 g/m^2
2. Booms	500 - 5000 $N\text{-}m^2$ @ 100g/m
3. Sail Assembly and Deployment size	50m- 400m- dia
4. Control	Propellantless control of roll, pitch, and yaw.
5. Navigation	Flight quality trajectory and navigation s/w

Objective:

The overall objective is to validate that large sail structures can be deployed in space from small containers, and that sail fabrication and packaging can be done at an affordable cost in a small volume. This validation will be accomplished by deploying a lightweight solar sail so that its in-orbit dynamical behavior can be observed and recorded. It should show that the sail deploys in the expected shape without tearing or ripping of the film, without unintended boom deformations, and without unplanned loads on the film or booms.

The observed deployment can then be compared to pre-launch predictions from computer models enabling an assessment of expected sail loads and behavior in space compared to expected values. The necessary diagnostics need to be provided so that this controlled solar sail deployment in zero-g can be documented for the characterization of the deployment dynamics and post-deployment structural behavior (mechanical, dynamical, and thermal).

Validation/Performance Requirements:
To accomplish this objective, the following data is needed.

- ?? Characterize the management and behavior of a stowed film (sail) as it is deployed:
  - Controlled release of film and booms;
  - Film tension, boom loading and structural characteristics;
  - Dynamics and reactions to induced perturbations and thermal environments; and
  - Models to predict deployment and post-deployment structural dynamics.
- ?? Obtain measurements of:
  - Boom and sail structure natural frequencies;
  - Boom bending stiffness;
  - Film stress during deployment and after deployment;
  - Dynamic modes in sail vibrations and responses to external forces; and
  - Thermal performance, including expansion and shrinkage of the sail, and temperature as a function of solar input.

To ensure that the data obtained from the test article during the validation mission can be extrapolated to the sizes of sails needed for future missions, the sail to be deployed in the validation mission should have the characteristics shown in Table 1-2.

Table 1.2: Solar Sail Validation Test Requirements

Area:	~ 40m x 40m
Stowed volume:	~ 40cm x 40cm x 80cm
Experiment mass: (including power, communications data processing, safety inhibits and release mechanisms)	< 150 kg
Strut -	
Linear mass density:	~ 30 - 100gm/m
Bending stiffness:	~ 5000 N-m ^{2}
Areal density*: (including reflective or emissive coatings--if required):.	10 - 15g/m^2

* Areal density includes sail film, booms, film/boom attachments and film tensioning hardware, and any other sail/deployment mass that must remain with the sail or its host spacecraft; after the sail is deployed.

The validation of a solar sail deployment is applicable to missions such as: **ESS's** NO mission; and **SEC**'s SPI, ISP, GSRI, Sub-L_1S, PASO, SF, IHC, OHRI, ISTB missions.

2. (*Draft*) LIGHTWEIGHT HIGH VOLTAGE (LHV) SOLAR ARRAY

Introduction:

Electric power is a fundamental resource for all space missions. The power subsystem on most spacecraft constitutes a substantial mass fraction of the total spacecraft mass. In the NMP DS1 project, a SCARLET array was validated. Its characteristics are shown in Table 2-1. A factor of three increase in the SCARLET array capability is needed for the next step of technology advance.

High voltage outputs for solar arrays are desirable, e.g., when supplying power to high-voltage ion propulsion subsystems, the mass required for power processing is reduced.

Objective:

The objective of this project is to validate the controlled deployment, in zero-g, of a lightweight high voltage solar array that is a fraction of a full-sized (~7kW-class) array, and greater than three times the SCARLET array's power density and output voltage shown in Table 2-1. Model(s) to predict the measured on-orbit characteristics listed below should also be developed and validated. Deployment dynamics and post-deployment structural behavior should be characterized by observing the way the array deploys and behaves in zero-g. It should also be shown that the array deploys in the expected configuration without damage or excessive loads to any components.

Table 2-1: Solar Array Capabilities

Array Type	Power Density (Watts/kg)	Array Output (Volts DC)
SCARLET array:	50	~ 100

Validation Objective/Performance Requirements:

To accomplish the objective of this flight validation, the following on-orbit data are needed:

?? Characterization of the management and behavior of a stowed array as it deploys:
- Measure dynamics of the deployed solar array, e.g., by using spacecraft thruster firings for excitation, and measure vibrational frequencies with accelerometers or other instrumentation;
- Controllability of array deployment;
- Substrate tension, structural loading and structural characteristics;
- Verification of support structure rigidization, if applicable
- Dynamics and reactions to induced perturbations and thermal environments; and
- Models to predict deployment and post-deployment structural dynamics.

?? Obtain measurements of:
- Voltage and current output of the array;
- Array structure natural frequencies;
- Structural bending stiffness;
- Substrate stress during deployment and after deployment;
- Dynamic modes in array vibrations and responses to external forces;
- Thermal performance, including thermal deformations in the array, and array temperatures as a function of solar input;
- Array structure linearity and straightness; and

– Space environmental effects on array performance.

To ensure that the data obtained from the test article during the validation project can be used to extrapolate to the sizes of arrays needed for future missions, the array to be deployed in the validation mission should have the characteristics shown in Table 2-2.

Table 2-2: Solar Array Requirements

Design:	Capable of producing ~ 7 kW that will lead to achieving a power density goal of 175 W/kg and 300 volts at 1 AU and also capable of operating at ~ 5 AU from the Sun
Validation test article:	Populated area capable of providing at least 500 W electric at 1 AU
Stowed Volume:	Minimize stowed volume
Mass:	Minimize experiment mass, including power, communications, data processing, safety inhibits and release mechanisms

The validation of a lightweight high voltage solar array is applicable to missions such as: **ESS's**: CNSR, NO, SRO, TE, VSSR.

3. *(Draft)* DEPLOYABLE AND INFLATABLE BOOMS

Introduction:
Ultra-lightweight deployable/inflatable structures are needed for magnetometer/instrument booms, solar sails' membrane support members, telescope sunshields, large aperture membrane optic telescopes structural members and antennas. The completion of this validation will facilitate the infusion of these technologies into full-up inflatable/deployable systems.

A space flight experiment is needed to:

?? Characterize deployment dynamics of long booms in microgravity environment because microgravity deployment dynamics cannot be simulated in ground testing.
?? Demonstrate uniformity and completeness of rigidization in the space environment.
?? Characterize the structural mechanics and dynamics of deployed booms in microgravity environment to validate analytical models developed in ground testing.
?? Demonstrate active control of structural dynamics to suppress vibrational modes that could adversely impact spacecraft attitude and pointing control.
?? Measure contamination resulting from outgassing during deployment and rigidization.

Potential candidate technologies for validation are:

?? Inflatable rigidizable tubes such as:

  - Thermoset composites
  - Thermoplastic composites
  - UV cured composites
  - Shape memory composites
  - Aluminum laminates
- ?? Isogrid tubes
- ?? Inflatable trusses
- ?? Strain energy deployed booms
- ?? Smart inflatables with integrated actuators and sensors to:
  - Demonstrate active control of structural dynamics
  - Demonstrate correction of post-deployment position errors before rigidization

Objectives:
The objective for validating deployable/inflatable structures technology is to provide a 2x reduction in mass, and 3x-5x reduction in packaging volume.

Validation Performance Requirements:
The article(s) to be validated should include a variety of inflatable/deployable tube and truss configurations fabricated from different rigidizable materials. Multiple deployments (~3-5) of identical test articles may be desired to demonstrate reliability/repeatability.

To accomplish the objective of this validation flight, data are needed to:
- ?? Characterize the deployment dynamics of deployable/inflatable booms in microgravity environment by validating:
  - The rigidization of booms by measuring the time to rigidize, and determining the uniformity of rigidization
  - Scaling laws by deploying booms of different length/diameter ratios
  - Reliability and repeatability by deploying several booms of the same type
- ?? Characterize the structural dynamics of deployed booms/trusses in microgravity environment to correlate with ground test results.
- ?? Characterize the straightness and rigidized length of the booms.
- ?? Characterize the active control of structural dynamics and geometry with embedded actuators.
- ?? Assess the effects of the space environment on rigidizable composite materials.
- ?? Other desired derived verification data includes:
  - Inflation pressure (if applicable)
  - Rigidization temperature profile (if applicable)
  - Structural modes
  - Vibrational frequencies
  - Deployment dynamics record

The characteristics of the deployable and inflatable booms needed for validation are found in Table 3-1.

Table 3-1: User Community Deployable and Inflatable Boom Requirements

Linear mass density:	30 - 50 g/m.
Length-to-diameter (L/D) ratios*:	Length: 2 meters, at L/D = 10 Length: 20 meters, at L/D = 100

* Test articles size should have several different length-to-diameter (L/D) ratios to validate scaling laws.

The validation of deployable and inflatable booms is applicable to missions such as: **ASO's** TPF, FAIR, LF, SUVO; **ESS**'s NO; **SEC's** GEC, GSRI, RAM, SPI; and **SEU's** ARISE, CON-X, SPIRIT, OWL.

4. (*Draft*) MEMBRANE OPTICS DEPLOYMENT

Introduction:
Future space observatories will require 1000x greater collecting area than existing telescopes to image extra-solar planets and to study the early universe. A critical metric driving the cost of large space telescopes is the areal density of the primary mirror. The areal density of state-of-the art lightweight optics technology is around 15 kg/m^2. Membrane mirrors have the potential to achieve areal densities of less than 1 kg/m^2, which would enable 25m-40m class telescopes by significantly reducing manufacturing and launch costs

An important step in the overall development of membrane optic systems is to characterize their on-orbit deployment behavior so that, once this is well understood, the remaining system aspects of controllability, structural rigidity to maintain membrane/mirror flatness, thermal control, etc. can be developed.

To accomplish this deployment characterization, a space flight experiment is needed to:
?? Validate packaging and deployment concepts for membrane optics, and understand the factors limiting scalability to very large sizes; and
?? Measure the effects of microgravity, thermal deformations, and deployment errors on optical surface precision. Combined effects of space environment cannot be simulated in ground testing. Knowledge of factors limiting achievable surface precision is needed for design of adaptive optical systems to control mirror shape and to correct wave front errors.

Objectives:
The flight validation of this technology is to characterize the factors limiting achievable surface precision of membrane mirrors so that adaptive systems can be designed to control mirror shape and correct wave front errors. This validation flight is a precursor that will lead to future flights to demonstrate a sub-scale membrane mirror telescope with an integrated adaptive optical subsystem.

Validation Performance Requirements:
The optical performance of a membrane mirror is degraded by surface distortions caused by deployment errors, thermal deformations, and microgravity effects.

To accomplish the objective of flight validating the deployment of a membrane mirror, the following data are needed:
?? Characterization of the deployment of a membrane mirror in the microgravity environment;
?? Quantification of the mirror surface distortions caused by deployment errors, thermal deformations, and microgravity effects;
?? Measurement of membrane dynamics;
?? Measurement of the mirror surface reflectivity; and
?? Assessment of the effects of the space environment on membrane mirror materials.

To ensure that the data obtained from the test article during the validation project can be used to extrapolate to the mirror sizes needed for future missions, NASA believes that the membrane mirror to be deployed in the validation project should have the characteristics found in Table 4-1.

4-1: Membrane Mirror Requirements

Diameter:	~ 2 m
Areal density:	~ 1 kg/m^2
Deployed surface accuracy:	? /20 with a goal of ? /40.

The validation of membrane optics deployment is applicable to missions such as: **ASO**'s FAIR, LF; **SEC**'s SISP; and **SEU**'s SPIRIT, CON-X, HSI, MAXIMPF.

5. (*Draft*) ULTRA LOW POWER (ULP) ADVANCED ELECTRONICS

Introduction:
The development of the ultra low power electronics capable of performing non-volatile memory, serial bus interfaces and high speed processor functions is needed to support the closure of the gap that exist between present day small spacecraft technologies and the low power needs for tomorrow's more complex missions.

A critical factor affecting the performance of low power electronics in the space environment is their response to Single Event Upsets (SEU). The effects of SEUs in ultra low-power semiconductor components cannot be fully simulated on the ground, and methods designed into the electronics for mitigating or countering their effects should be verified in the space environment.

Objective**:**
The objective is to fly these new technologies so that their on-orbit requirements shown in Tables 5-1A, B, C can be verified and documented and thereby, provide a clear path to their use in a multiplicity of missions from low Earth orbit to deep space.

Table 5-1A: Non-volatile Memory Requirements

Memory capacity:	8 Gbits
Power:	< 1 watt
Input voltage:	< 3.3 VDC
Mass:	200 grams

Validation Performance Requirements:
To ensure that the validation electronic articles spend as much time in the validation environment, an orbit that presents significant time spent in the SEU environment is highly desirable.

Table 5-1B: Serial Bus Requirements

Data rate:	> 5 Mbps
Power:	< 2 watts
Input voltage:	< 3.3 VDC
Type of receivers:	Mixed signal, RS-485
Number of multi-drop nodes:	$\geq$32

New approaches to achieving reliability, such as a combination of radiation hardened and radiation tolerant electronic components can implement a fault tolerant memory element. These and other concepts for achieving ultra low power, as well as low cost, are encouraged.

Table 5-1C: High Performance Processor Requirements

Processing capability:	> 300 MIPS
Power:	< 2 watts, typical
Single event latch-up:	Immune
Input voltage:	< 3.3 VDC

Data obtained from this validation flight should permit extrapolation of performance over a mission life of 5 or more years.

The validation of ultra low power advanced electronics is applicable to missions such as: **ESS**'s CNSR, EL, NO, SRO, MSR, TE, VSSR; and **SEC**'s GEC, MC (SN)

6. (*Draft*) MINIATURE ENERGY-SAVING THERMAL CONTROL SUBSYSTEM

Introduction:
At present, thermal control systems reject heat from hot components to space using radiators and use heater power to heat cold components. The use of a miniature energy-saving thermal control subsystem that transfers heat from hot to cold components represents an implementation shift that will greatly reduce spacecraft system power requirements and mass. This subsystem employs advanced transport loop and variable emissivity technologies. The use of a thermal control subsystem based on these advanced technologies will reduce the spacecraft mass and power by 3% to 15% compared with current technologies.

Objective:
The objective is to validate a miniature integrated thermal control subsystem that transfers heat from hot to cold components while rejecting excess heat to space. The key advanced technology components of the subsystem are: a passive two-phase heat transport loop , passive thermal control valve, and variable emissivity device. This technology has the potential to reduce the thermal and mechanical constraints imposed on present spacecraft by providing configurational design flexibility in the location of hot and cold components. The ability of advanced variable emissivity devices to perform as an integral part of the subsystem is subject to space environment effects caused by radiation, UV, and atomic oxygen.

Validation Performance Requirements:
Characterize the operation of two phase heat transport devices and variable emissivity devices within an integrated subsystem in modes that replicate flight conditions. Heat transport/variable emissivity devices of different types or of the same type but from different manufacturers may be validated to assess uncertainties in space performance of differing technologies and/or variations in design features of a selected technology

The miniature thermal control subsystem should have the following capabilities:

?? Transfer heat passively, dissipate up to 50 Watts of power, and weigh less than one kilogram including the radiator;
?? Transfer heat from a source to a sink and/or radiator;
?? Transport heat through pipes that are flexible so that the thermal control subsystem can be easily adapted to a small spacecraft;
?? Control the temperature to within a 2 to 4°C tolerance; and
?? Radiate heat using a variable emissivity device that weighs less than 500 $g/m^{2.}$

The validation of a miniature energy-saving thermal control system is applicable to missions such as: **ESS**'s CNSR, NO, and TE.

7. (*Draft*) WIDEBAND OPTICAL COMMUNICATIONS

Introduction:
Optical communications subsystems present a paradigm shift in communications systems, due to their shift away from the traditional technology of communications while offering superior data

handling capability to the current radio frequency (RF) communications systems. Optical communications subsystems have the following advantages over a RF communications subsystem:

?? Power Reduction: 3X to 4X
?? Increase Data Rate: 10X
?? Aperture Size Reduction: 10X
?? Mass Reduction: 2X
?? Reduced manufacturing cost

Due to the uniqueness of optical communications space flight validation is necessary because:

?? Validation of the most critical subsystem requirements, i.e., acquisition, tracking and pointing, is possible only from space over very large relative ranges
?? Link availability due to cloud attenuation and other atmospheric effects should be demonstrated from space

Objectives:
Demonstrate optical communications technologies that will enable next generation data services at an order of magnitude increase in data rates for both near-Earth and interplanetary space science missions.

Validation Performance Requirements:
Characterize and validate the performance of an optical communications subsystem as it would be used on a spacecraft to perform high bandwidth communications from the spacecraft platform to the ground. Also, validate the ground based modeling of the communications link, and support the following performance requirements:

?? Mass: < 40 kg
?? Power: < 70 W
?? Approximate Volume: 20 cm x 20 cm x 30 cm
?? Acquisition, Tracking and Pointing:
    – Near Ranges (Earth): 0 - 1 AU
    – Far Ranges (deep- space): >1AU
?? Data rate: 1-10 Gbps.

The validation of wide band optical communications is applicable to missions such as: **ESS**'s CNSR, NO, SRO, EL, VSSR; **SEC**'s ISP; and **SEU**'s ARISE.

8. (*Draft*) SECONDARY BATTERIES FOR DEEP SPACE MISSIONS

Introduction:
For space science missions having long lifetimes (>10 years) special attention needs to be focused on validating advanced batteries to meet these lifetimes, and high cycle life (>30,000) requirements. Ni-Cd and Ni-H2 batteries now used have an energy density of 30 to 40 Wh/kg. Newer batteries, such as Li-ion and Li-polymer batteries, have energy densities between 150 and 250 Wh/kg (~5X greater) and volumes one-tenth the volume of Ni-H2 batteries. Tests in microgravity to provide data for correlation with ground tests are needed to determine lifetime characteristics such as the distribution of electrolytes within battery cells.

Objective:

Validate high energy density, lightweight secondary battery technology that will enable next generation power subsystems to support long duration missions with or without high cycle life. The batteries need to be capable of operating with both high and low charge-recharge cycle rates and over broad temperature ranges. Minimum operating temperatures are desirable for deep space missions to minimize thermal control heating requirements. Because the mission requirements are diverse, two types of battery requirements are specified in Table 8-1 below.

Validation Performance Requirements:

The performance requirements for batteries selected for flight validation are given in Table 8-1. Measurements shall include characterizing battery performance at the cell level. A test that compares ground based test results with those measured in space should be included so as to validate the ground-based tests and thus reduce the need for future flight validation. These tests should include accelerated test approaches that determine the battery long life capability such as:

Table 8-1: Secondary Battery for Deep Space Missions Performance Requirements

REQUIREMENT	**TYPE I**	**TYPE II**
Cycle Life	> 30,000	> 300-500
Shelf Life	> 7 yr	> 15 yr
Depth-of-discharge (DOD) max	20-60%	80%
Radiation	0.1 Mrad	1 to 10 Mrad
Specific Energy Goal (100% DOD)	150 Wh/kg	
Amp-Hour Capacity	5 to 50 Ah	
Charge-Discharge Energy Efficiency	> 90%	
Normal Operating Temperature	-10 to +30°C	
Extreme Operating Temperature	-20 to +50°C	
Voltage Range with Battery Connected to Unregulated Bus	22 to 36 V	

?? Operating mode measurements: Operate batteries in modes that replicate flight conditions including charge/recharge cycles and depth of discharge.

?? Extreme temperature measurements: Operate batteries in space at temperature extremes to identify potential failure modes.

The validation of a Secondary Battery technology that meets the requirements identified above increases the probability of performing and/or significantly improving space science missions operating far from Earth.

9. (*Draft*) AUTONOMOUS RENDEZVOUS

Introduction:

Current rendezvous capabilities developed for both the US and Russian human space programs require extensive ground control involvement in set-up to approach, and for US missions, final approach/contact control. Both the US and Russian techniques depend on high mass, high-power radar or visual crew sensors. Current automated rendezvous techniques developed by the Japanese require GPS and also depend on high mass, high-power sensors. Due to the physical limitations of current rendezvous technology, they are not applicable to small and medium size spacecraft.

Basic sensors of different types have been demonstrated in breadboard form in ground tests, in the laboratory, and in the field. Algorithms for data analysis and control have been simulated in mission contexts that reflect most expected uses.

Individual component technologies needed for autonomous rendezvous can be tested for functional performance in existing ground facilities. Demonstration in space is needed to show that the components can function together at the ranges, lighting conditions, and radiation fluxes that will be expected in an operationally relevant environment. These conditions, coupled with the three-dimensional orbital dynamics and drag-free environment, are not available in ground facilities and are the final validation of viable performance for autonomous rendezvous capability.

Objective:

Demonstrate automated in-space rendezvous with both cooperative and natural targets. Specifically, demonstrate the capability to rendezvous with a cooperative, non-maneuverable sample return canister in a known planetary parking orbit. In addition, the capability is sought to rendezvous with a natural target such as a comet or other small body in a known orbit. The capability need includes the sensing hardware that would reside on a maneuverable chase vehicle, the hardware that would reside on a cooperative target, and the associated software for processing the sensor data and executing the rendezvous profile with either the cooperative or natural target. The provided capability should be compatible with, and offer the potential to accommodate, needs broader than rendezvous to include proximity operations and landing hazard avoidance.

Validation Performance Requirements:

Fly an active sensor package on a maneuverable host vehicle in Earth orbit to validate its ability to meet the requirements shown in Table 9-1. In addition, demonstrate operation of each sensor to:

?? Characterize sensor performance in the space environment while detecting cooperative and natural targets over a set of relevant distances and orbit geometries;
?? Provide the host vehicle with target information input to guidance and control algorithms;
?? Validate specific types of control algorithms for rendezvous and proximity operations; and
?? Assess mission support requirements for successful operations.

Table 9-1: Autonomous Rendezvous Validation Requirements

Functional

- Determine 3D position and velocity with respect to sample canister or target body surface
- Minimize the potential for collision or hazardous contact with the sample canister or target body surface
- Provide for operation through dust clouds (coma)

Performance

Operating Range:	5 km to 0.5 m
Accuracy (3D, 3 sigma):	5 m (Range 5 to 2 km); 0.25% range (Range 2 km to 10 m); 2.5 cm (Range < 10 m).
Range and Transverse Rate:	1-10 cm/s for large bodies 1 cm/s for small body (e.g. asteroid)
Time to Reacquire Sample Canister:	
Within 2 pi Field of Regard:	1000 s (all ranges).
Within 10 X 10 deg Field of Regard:	5-50 s

Physical

Chase-Vehicle Resident Hardware:	
Mass:	< 4 kg
Power:	< 25 W continuous, active
Volume:	< 4000 cc
Cooperative Target-Resident Hardware:	< 10 - 100 g

The validation of autonomous rendezvous is applicable to missions such as: **ASO**'s Potential TPF; and **ESS**'s CNSR, EL, MSR, VSSR

10. (*Draft*) ON-BOARD DATA PROCESSING TO REDUCE DOWNLINK AND MISSION OPERATIONS STAFF

Introduction:

Due to the ever increasing complexity and sophistication of space missions, the amount of "raw" data desired to be collected and downlinked is beginning to surpass the onboard and ground communications subsystem's capabilities to handle the data. On-board data processing provides a path to ameliorate this ever-increasing demand being placed on the spacecraft-to-ground communications subsystem, but current capabilities are limited to:

?? Calibration and error correction of engineering sensor data;

?? Onboard data compression and pre-specified filtering, e.g., frequency sampling and pre-programmed processing on simple event detection.
?? Routine attitude determination data fusion (combining data from multiple sensors creating additional knowledge of the environment).

On DS1, there was a limited amount of fusion of navigation data with attitude determination data, but it required considerable ground support. Long-term trending and identifying unanticipated events is all done on the ground. There was no capability to capture persistent sensor anomalies and analyze them.

The potential benefits afforded by On-board Data Processing can only be realized through an understanding that the use of On-board Data Processing:
?? Is a paradigm shift from ground to onboard processing of data with data-driven decision making on-board;
?? Permits real-time reasoning about, and adjustments to, spacecraft capability, environmental dynamics, and mission priorities;
?? Involves complex interactions between spacecraft assets, states and resources, and their adaptation to the observed space environment and to the mission goals; and
?? Will significantly increase the probability of mission success if critical, interdependent, On-board Data Processing technology elements are flight proven.

The technology sought is expected to offer an entirely new capability.

Objective:
The objective for validating On-board Data Processing technology is to demonstrate its many potential benefits to future missions that include:
?? Complex mission activities such as intricate deployments that demand monitoring and adjustment of resources due to competing demands.
?? Mission scenarios that are dependent on event-triggered activities.
?? On-board data analysis from distributed sensors to determine global environmental characteristics.

The data processing capabilities, are listed below in order of increasing significance:
1. Calibration and error correction of engineering sensor/instrument data
2. Engineering sensor data-fusion for guidance navigation and control
3. Spacecraft health data analysis--determination of component, subsystem and system state and the development of a mechanism (e.g., compression, summarization, data products) for monitoring, reporting and archiving the information
4. Mission engineering data summarization
5. Spacecraft resource management and optimization
6.On-board re-targeting to repeat science observations
7.Guidance navigation and control and science observations in uncertain/hostile environments such as real-time hazard avoidance and path re-planning
8. Adaptation to unexpected environment to take advantage of serendipitous science or maximize science return

Validation Performance Requirements:

To validate this technology, the following requirements and capabilities of an Onboard Data Processing subsystem need to be an integral part of a flight validation program:

?? Provide at least an order of magnitude reduction in down-link data rate (or at least an order of magnitude increase of information at the same data rate)
?? Maintain the integrity of the data
?? Include a data prioritization method
?? Provide a fault tolerance approach to reduce the risk of information loss
?? Incorporate a means for incorporating/changing/modifying data processing algorithms
?? Include features that are adaptable across missions and during long duration missions
?? Reduce by a factor of ten (10) the time delay from science data capture to "first-look" by mission scientist
?? Enable at least 50% reduction in time to resume mission operations after mission interruption due to engineering anomaly compared to an equivalent ground-based information processing
?? Reduce by at least 50% the engineering set-up time for science observation

The validation of on-board data processing is applicable to missions such as: **ESS**'s CNSR, EL, NO, SRO, TE, VSSR; **SEC**'s GEC, ISP, MC, MMS, RAM, RBM, (PASO, SN); and **SEU**'s ARISE, CON-X, OWL

11. (*Draft*) AUTONOMOUS GOAL-BASED MISSION COMMANDING AND EXECUTION

Introduction:

Autonomous Goal-Based Mission Commanding and Execution has the potential for making a number of missions possible and other extremely complex ones less complex. Deep space missions requiring considerable interactive command activity are virtually impossible to implement due to the long transit time of commands and ground notification of command response. Multisatellite formation flying, whether near Earth or not, are complex missions to control especially for those requiring formation reconfiguration based on events. Autonomous Goal-Based Mission Commanding and Execution holds promise for these types of future missions.

The current level of onboard autonomous capabilities such as the DS1 Remote Agent demonstrated a limited level of autonomy, i.e., the generation and execution of sequences onboard. This was an experimental software module, which was not an integral part of the flight software. It required artificial intelligence specialists to both implement and operate, and the use of three separate modeling procedures, which were difficult for traditional flight software developers to implement. The realization of Autonomous Goal-Based Mission Commanding and Execution's potential to future missions is dependent upon reducing the overall complexity of its implementation and use.

Objective:

Demonstrate intelligent deployable planning and execution agents. The capabilities needed include:

?? Intelligent autonomous operations in uncertain/hostile environments
?? Model-based planning and execution

?? Migratable flight/ground automated planning
?? Dynamic planning and plan optimization
?? Contingency planning due to uncertainty in resource needs and availability
?? Planning that accommodates environmental uncertainties and complex task dependencies

It is important to note that the Autonomous Goal-Based Mission Commanding and Execution subsystem holds the promise for a significant reduction in the complexity of missions to deep space and/or flying interactive clusters of spacecraft by:

?? A paradigm shift in mission operations; mission goals are achieved through automated planning, re-planning, automated task elaboration, and automated mission activity execution.
?? Permitting real-time reasoning about, and adjustments to, spacecraft capability, environmental dynamics and science priorities.
?? Managing the complex interactions between spacecraft assets, states and resources and their adaptation to the observed space environment and to the mission goals.

This is a revolutionary way of planning and conducting mission operations; therefore, it presents a high risk to strategic missions if critical interdependent technology elements are not flight proven.

Validation Performance Requirements:

Since Autonomous Goal-Based Mission Commanding and Execution is directed at reducing mission complexity, its validation needs to incorporate:

?? Complex mission activities such as intricate deployments/observations that demand monitoring and adjustment of spacecraft dynamics or intricate payload adjustments while maintaining given constraints.
?? Scenarios that are dependent on external inputs to complete mission goals.
?? System "instrumentation" both on the ground and in-flight for technology validation.

In addition, Autonomous Goal-Based Mission Commanding and Execution should be:

?? Significantly advanced to enable missions currently unattainable due to excessive command and control space link transmission times (for example dynamic fast re-planning during encounter), and to reduce mission operations staffing by a factor of five
?? Limited in its implementation requirements to the same order of impact on the project as traditional flight software in terms of demands on:
  - Development infrastructure
  - Integration with other software modules
  - Validation at the system-level
  - Compatibility with software practitioner skills

Further, the computational resources should be of the same order as traditional flight modules such as the attitude and control subsystem and fault protection, and the response time to plan development must be quantifiable.

The validation of autonomous goal-based mission commanding and execution is applicable to missions such as: **ESS**'s CNSR, EL, NO, SRO, TE, VSSR; **SEC**'s ISP; and **SEU**'s OWL, MAXIMPF.

12. (*Draft*) MODEL-BASED FAULT PROTECTION FOR COMPLEX SYSTEMS

Introduction:
Current capabilities of fault protection spacecraft elements are limited to autonomous switching from redundant component A to B allowing recovery of the higher-level mission activities for simple mission phases such as cruise. During encounter mission sequences, higher-level mission activities cannot be recovered resulting in mission failure unless correctable by ground intervention. Currently, point designs for critical sequences are developed, which are extremely expensive.

Increasing the robustness of spacecraft and reducing the number of ground personnel responsible for the "intense operational support" of the spacecraft requires:

?? A paradigm shift in mission fault protection; mission robustness is achieved by the modeling of spacecraft system-level and subsystem-level capabilities and reasoning about automated responses to restore functionality.
?? Permitting the spacecraft to perform real-time reasoning to find acceptable degradations to adapt to environmental changes and meet mission priorities.
?? The involvement of complex interactions between spacecraft assets, states and resources, and their adaptation to the observed space environment and to the mission goals.

The absence of validating this technology presents a high risk to strategic missions if critical interdependent technology elements are not flight-proven.

Objective: Demonstrate technologies for automated monitoring, diagnosis and recovery of complex systems. The capabilities needed include:

?? Automated on-board, model-based, as opposed to procedural, e.g., "if…then…" approaches to fault identification, diagnosis and recovery
?? Robust high-level, goal-directed commanding instead of low-level sequences

Validation Performance Requirements:
Since Model-Based Fault Protection is directed at reducing mission complexity while increasing spacecraft robustness, its validation needs to incorporate:

?? Complex mission activities such as intricate deployments/observations that demand monitoring and adjustment of spacecraft assets due to competing demands or simulated failures.
?? Scenarios that are dependent on external inputs to complete mission goals.
?? System diagnostics both on the ground and in-flight for technology validation.

In addition, the Model Based Fault Protection software should be:

?? Significantly advanced to increase mission robustness and limit spacecraft safing to situations where on-board healthy assets cannot provide a path to continue the mission
?? Limited in its implementation requirements to the same order of impact on the project as traditional flight software fault protection, with the computational resources being of the same order as traditional flight fault protection modules

The validation of model-based fault protection for complex systems is applicable to missions such as: **ESS**’s CNSR, EL, NO, SRO, TE, VSSR; **SEC**’s RAM, SDO, ISP; and **SEU**’s ARISE, CON-X, OWL

13. (*Draft*) DILUTION CRYOCOOLERS

Introduction:
Dilution cryocoolers and magnetic coolers operate in the same sub-Kelvin temperature range. Both types have been demonstrated in the laboratory. However, magnetic coolers require magnets, which add mass and interfere with science measurements from instruments such as magnetometers. For space operations, a continuous or closed-cycle dilution cryocooler is desirable particularly for applications requiring extended periods of operation at sub-Kelvin conditions.

An open-cycle type dilution cryocooler has been developed, and is being implemented on the Planck mission, but its operational life is limited by the quantity of expendendable 3He and 4He crycooler fluids carried.

Closed cycle dilution cryocoolers capable of operating continuously in the sub-Kelvin range have never been flown in space, and thus, their successful flight validation would increase confidence in their use. A single-cycle prototype with necessary porous material for controlling the liquid Helium has been demonstrated in the laboratory, and is being modified to operate continuously. The closed-cycle dilution cryocooler may be gravity sensitive because of the need to mix and separate the 3He and 4He; hence, cooler space performance is difficult to verify on the ground; therefor, space flight validation is needed.

Objective**:**
Demonstrate continuous dilution cryocooler technologies that are suitable for cooling advanced detectors requiring cooling to sub-Kelvin temperatures in space for long time periods with no vibration and zero magnetic field.

Validation Performance Requirements:
The validation effort should include ground and flight correlation tests to demonstrate the following dilution cooler performance parameters:
?? Operating temperature range and associated input power
?? Operational sequence and cycling
?? Cooling power efficiency
?? Cooler heat sink requirements
?? Cooler volume and mass
?? Cooler mechanical robustness due to launch vibration
?? Cooling capability: 50 mK - 300 mK.
?? Cooler stability: ~10 microK
?? Cooler mass: < 10 kg
?? Cooler lifetime: > two years
?? Cooler Load 1 – 10 microWatts

The dilution cooler should be suitable for cooling miniature detectors such as the superconducting TES (Transition Edge Sensor) calorimeter for mm and submm waves and bolometer for X-ray detection in microgravity environment.

The validation of dilution crycoolers is applicable to missions such as: **ASO**'s FAIR, SUVO; and **SEU**'s CON-X, MAXIMPF, SPIRIT, (ACT, SPECS)

Missions

Acronym	Mission	Time Frame	Status	Theme
ACT	Advanced Compton Telescope	Far Term	Roadmapped by Theme Only	SEU
ARISE	Advanced Radio Interferometry between Space and Earth	Mid Term	In Strategic Plan	SEU
CNSR	Comet Nucleus Sample Return	Mid Term	In Strategic Plan	ESS
Con-X	Constellation-X	Mid Term	In Strategic Plan	SEU
EL	Europa Lander	Mid Term	In Strategic Plan	ESS
FAIR	Filled Aperture Infrared (Capability Concept)	Far Term	In Strategic Plan	ASO
GEC	Geospace Electrodynamic Connections	Near Term	In Strategic Plan	SEC
GSRI	Geospace System Response Imager	Far Term	In Strategic Plan	SEC
HSI	High Resolution Spectroscopy Mission	Mid Term	In Strategic Plan	SEU
IHC	Interheliospheric Constellation	Far Term	Roadmapped by Theme Only	SEC
ISP	Interstellar Probe	Mid Term	In Strategic Plan	SEC
ISTB	Intersteller Trail Blazer	Mid Term	In Strategic Plan	SEC
ITM Waves	Ionosphere-Thermosphere-Mesosphere Waves Probe	Mid Term	In Strategic Plan	SEC
LF	Life Finder	Far Term	In Strategic Plan	ASO
MAXIM	MicroArcsecond X-ray Imaging Mission (/Pathfinder)	Far Term/ Mid Term	In Strategic Plan	SEU
MC	Magnetospheric Constellation	Mid Term	In Strategic Plan	SEC
MMS	Magnetoperic Multiscale	Mid Term	In Strategic Plan	SEC
MSR	Mars Sample Return	Mid Term	In Strategic Plan	ESS

Acronym	Mission	Time Frame	Status	Theme
NGST	Next Generation Space Telescope	Mid Term	In Strategic Plan	ASO
NO	Neptune Orbiter	Mid Term	In Strategic Plan	ESS
OHRI	Outer Heliospheric Radio Imager	Far Term	Roadmapped by Theme Only	SEC
OWL	Orbiting Array of Wide-angle Light Collectors	Mid Term	In Strategic Plan	SEU
PASO	Particle Acceleration Solar Orbiter	Far Term	Roadmapped by Theme Only	SEC
RAM	Reconnection and Multiscale Probe	Mid Term	In Strategic Plan	SEU
RBM	Radiation Belt Mappers	Far Term	In Strategic Plan	SEC
SDO	Solar Dynamics Observatory	Near Term	In Strategic Plan	SEU
SN	Sentinels	Far Term	Roadmapped by Theme Only	SEC
SF	Solar Flotilla	Far Term	Roadmapped by Theme Only	SEC
SP	Solar Probe	Near Term	In Strategic Plan	SEU
SPECS	Submillimeter Probe of the Evolution of Cosmic Structure	Far Term	Roadmapped by Theme Only	SEU
SPI	Solar Polar Imager	Mid Term	In Strategic Plan	SEU
SPIRIT	Space InfraRed Interferrometric Telescope	Mid Term	In Strategic Plan	SEU
SRO	Saturn Ring Observer	Mid Term	In Strategic Plan	ESS
SISP	Stellar Imager and Seismic Probe	Far Term	Roadmapped by Theme Only	SEC
SubL1S	Sub-L1 Sentinal	Far Term	Roadmapped by Theme Only	SEC
SUVO	Space Ultraviolet Observatory (Capability concept)	Far Term	In Strategic Plan	ASO
TE	Titan Organic Explorer	Far Term	In Strategic Plan	ESS
TPF	Terrestrial Planet Finder	Near Term	In Strategic Plan	ASO
VSSR	Venus Surface Sample Return	Mid Term	In Strategic Plan	ESS